Go To Mars With Newton

In his well-known and universally acclaimed book, *The Principia*, Sir Isaac Newton proposed a way to launch an object into orbit. His method was to place a cannon on a mountaintop and fire cannon balls parallel to Earth's surface. By using more gunpowder each time, the cannon ball would fly farther before falling to the ground. Newton imagined increasing the gunpowder until the cannon ball took off with such a great initial speed that it fell all the way around Earth — the cannon ball went into orbit and became a cannon ball satellite. In fact, if the cannon ball was able to make it half-way around the world, it would continue to orbit.

Today, scientists do not use cannons and gunpowder to launch rockets, but Newton's method and his laws still apply. Launching a rocket into orbit simply requires that the trajectory of its "free fall" carry it around the globe. While the rocket continually falls toward Earth's surface, the surface itself continually curves away from the rocket's path. Orbital motion is much like a perpetual game of tag between the satellite and the planet's surface. If the speed of the satellite drops below the orbital speed, then the satellite's trajectory will lead it to an impact on the surface.

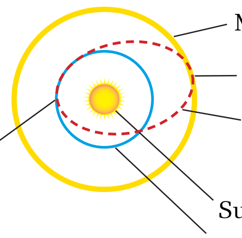
The speed required for an orbit close to Earth is around 28 000 km/h. Part of this can be provided by launching the rocket in an easterly direction from a location near the equator. As Earth revolves, its surface at the equator moves eastward at about 1675 km/h, thus providing a free, although relatively small, boost.

Lift-off involves the ignition of fuel and oxidizer in a reaction which is much like a controlled explosion. Hot, high pressure gas is formed as the product of the burning. When the high-speed molecules of the gas collide with the walls of the combustion chamber, they exert forces on the walls of the chamber. Because of an opening at one end of the chamber, the net force exerted by the gas molecules on the chamber is in the forward direction. By Newton's third law of motion, the chamber walls exert an equal and opposite force on the gas molecules, causing them to stream backward out of the nozzle at the end of the chamber. The nozzle controls the direction and rate of flow of the exhaust gases and so provides control of the direction and magnitude of the thrust. Once the thrust becomes greater than the weight of the rocket, the rocket begins to accelerate upward.

Once the fuel in the first stage has been consumed, that stage can be separated from the rest of the rocket and a second stage compartment is ignited. By letting the first compartment drop away, the rocket has less mass that needs to be propelled. Applying Newton's second law, which states that the acceleration is proportional to the ratio of the applied force and the mass, for the same amount of thrust, the rocket will accelerate more quickly.

Sending a Rocket to Mars

Contrary to popular opinion, the best time to send a spacecraft to Mars is not when Mars and Earth are closest in their orbits around the Sun. Instead, the launch opportunity occurs when the spacecraft can be fired tangentially from Earth's orbit, travelling along an elliptical orbit around the Sun, and arrive at Mars about 259 days later travelling tangentially to the orbit of Mars. The elliptical orbit is called a Hohmann transfer orbit. The Earth–Sun distance represents the closest point to the Sun (the perihelion) and the Mars–Sun distance represents the farthest point from the Sun (the aphelion). Energy is saved in two ways: The first is due to the use of Earth's orbital speed as the starting speed for the spacecraft. In fact, the spacecraft only needs an additional 3 km/s above the orbital speed of Earth around the Sun. The second comes from the fact that the average radius of the orbit of the ellipse is less than the orbital radius of Mars. If the spacecraft was not captured by the gravitational field of Mars, the spacecraft would continue along the ellipse and fall back toward its perihelion. It is thus necessary to launch the spacecraft such that its arrival time at aphelion coincides with the arrival of Mars at the same location. Such launch opportunities come only every 25 to 26 months.



In general then, the Hohmann transfer orbit only requires a burst of thrust when the spacecraft leaves Earth orbit and a second burst to allow it to settle into an orbit around Mars. Further manoeuvring would be required if the spacecraft was then going to land on the surface of the Red Planet. On its return, the spacecraft would drop away from Mars and follow the second half of the Hohmann transfer orbit back to Earth.

Making Connections

1. Describe how Newton's laws apply to a rocket at lift-off, in orbit, and landing.
2. (a) What differences would you need to consider to send a rocket to Venus instead of to Mars?
   (b) Draw a Hohmann transfer orbit for a rocket travelling to Venus.